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Natural weathering of cool coatings and its effect on solar reflectance of roof surfaces

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Abstract

With the aim of determining the changing in the reflectance of coatings submitted to weathering conditions, 20 specimens (cool and standard) were exposed to natural weathering for 18 months. Their spectral reflectances were measured in laboratory with a spectrophotometer each 3 months, and the solar reflectances were calculated for each sample. The results indicated a reduction in the coatings reflectance after weathering exposure for the analyzed period. The results suggest the need of developing coatings able to maintain their reflective characteristics over time , increasing the potential of solar radiation reflection by these surfaces, and the reduction of buildings heat gains.

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Keywords: solar reflectance; cool roofs; thermal performance; coatings.

1. Introduction

Roof surfaces are responsible for significant portion of the total solar radiation absorbed by a building. Suehrcke et al. [1] emphasize that daytime heat flow from a sun-exposed roof surface is essentially only in downward direction and the downward heat flow generally is undesired, as it tends to overheat the building or put extra load on an air-conditioning system. In particular, use of light-colored roofing materials has been shown qualitatively to have the potential for reducing solar heat gain and hence air-conditioning cooling loads [2].

The use of reflective materials on the building envelope is one of the most efficient ways to reduce these effects. Envelope reflectances determine the effect of solar radiation in buildings, because they indicate which portion of the

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solar energy that hits the envelope is actually absorbed by the exterior surface. The solar absorption affects the building's heat gains and indoor temperatures, and which part is reflected, with no effect on the building thermal conditions. Additionally, solar heat gains of building opaque surfaces affect the indoor thermal comfort conditions for the occupants and consequently the energy consumption increase in conditioned buildings [3]. In this case, the most efficient way to reduce building heat gains is to control and minimize the solar radiation absorbed by the envelope [4].

According to Synnefa et al. [5], for peak solar conditions (about 1000 W/m²) for an insulated surface and under a low wind condition, the temperature of a black surface with solar reflectance of 0.05 (or 5%) is about 50°C higher than ambient air temperature. For a white surface with solar reflectance of 0.8, the temperature rise is about 10°C to the air temperature. Surface temperature measurements demonstrated that a cool coating (high solar reflectance) can reduce the concrete tile's surface temperature by 7.5°C and it can be 15°C cooler than a silver grey coating [5].

White roof coatings have been promoted for the benefit of reducing cooling load because of their high solar reflectance, as well as for the ability to protect the roofing surface from ultraviolet degradation. New materials have been compared with traditional ones in terms of color matching and near-infrared/solar reflectance. More specifically innovative paints can definitely improve the solar reflectance of building roofs and façades which could have poor reflective properties. Together with improved reflective properties, the innovative building coatings are also expected to have optimal aging resistance. Building materials are deeply subjected to atmospheric factors and ageing. Construction materials are multicomponent systems highly influenced by physical and chemical environmental effects. Durability is one of the main issues for new materials, also considering that the higher initial investment can be paid back by the yearly cooling energy saving only if reflecting properties are preserved over the time [6]. On the other hand, several researches have demonstrated that the roof exposure to environmental agents changes the roofs initial solar reflectance [7-11].

According to Bretz and Akbari [12], the solar reflectance is likely to decrease if the initial reflectance is high, because of surface accumulations and material degradation. Surface accumulations, such as dirt and microbial growth, may or may not be permanent, depending on their water solubility. Microbial growth is more common in humid areas. Degradation, however, may modify the solar reflectance permanently by inducing chemical change in the material. Insolation (particularly UV radiation), moisture (dew, rain, humidity), temperature (primarily the time-averaged temperature of the roof), and natural and anthropogenic pollutants (particularly aerosols and acid rain) are the major elements that degrade roof coatings. Earlier studies indicated that most of the solar reflectance degradation of coatings occurred within the first year of application, and even within the first two months of exposure.

In this paper, natural aging tests were performed on specimens of different cool and standard coatings exposed to weathering for 18 months. The spectral reflectances were measured in laboratory for the coatings, in order to identify the effect of reflectance degradation over time.

2. Method

2.1. Test specimens

In this work, 20 coatings commercially available in Brazil were evaluated. Twelve specimens are standard coatings (std.), including one formulated with ceramic microspheres, and eight specimens are cool acrylic coatings. In order to obtain results closer to real surfaces, the specimens were prepared with ceramic tablets (40 x 40 mm), with a smooth surface to avoid the roughness effect on the reflectance results. The selected samples are described in Table 1. All the coatings were not produced by the authors, they were obtained from the market.

2.2. Laboratory Measurements

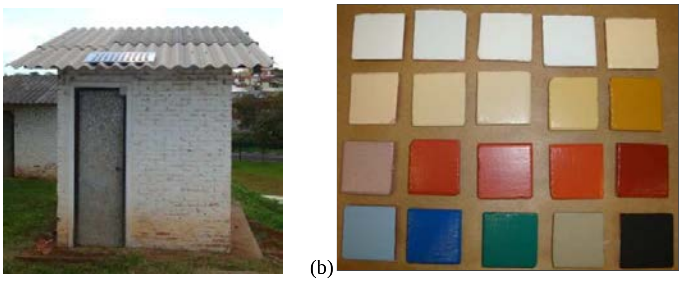
Spectral reflectance measurements were performed for the selected coatings with a double-beam spectrophotometer (Varian - CARY-5G) equipped with 150mm integrating sphere, considering both specular and diffuse radiation according to the ASTM E903-96 [13]. The reflectance was determined from 300 to 2500 nm, which is the solar spectrum range with the highest concentration of solar energy according to the ASTM G173-03 [14]. Spectral reflectance data obtained in this work were adopted to obtain the Solar Reflectance (SR) of each sample. The calculation was carried out by weighted-averaging, using a standard solar spectrum as the weighting function to compute the overall fraction of solar energy reflected under typical atmospheric conditions. The spectrum is that provided by ASTM G173-03. The samples prepared for this procedure were carefully painted to obtain homogeneous and uniform surfaces.

Table 1. Description of the selected coatings.

Sample	Sample description	Sample Color	Type	Sample	Sample description	Sample Color	Type
S1	Acrylic, elastomeric coating	White	Std.	S11	Acrylic, elastomeric coating	Rosy Brown	Std.
S2	Styrene acrylic coating	White	Cool	S12	Acrylic, elastomeric coating	Red	Cool
S3	Styrene acrylic coating	White	Cool	S13	Acrylic, elastomeric coating	Red	Std.
S4	Acrylic, elastomeric coating with ceramic microspheres	White	Cool	S14	Acrylic, elastomeric coating	Red	Cool
S5	Acrylic, elastomeric coating	White sand	Cool	S15	Acrylic, elastomeric coating	Dark red	Cool
S6	Acrylic, elastomeric coating	White sand	Std.	S16	Acrylic, elastomeric coating	Light blue	Std.
S7	Acrylic, elastomeric coating	Sand	Cool	S17	Acrylic, elastomeric coating	Dark blue	Std.
S8	Acrylic, elastomeric coating	Sand	Std.	S18	Acrylic, elastomeric coating	Dark green	Std.
S9	Acrylic, elastomeric coating	Yellow	Std.	S19	Acrylic, elastomeric coating	Dark grey	Std.
S10	Acrylic, elastomeric coating	Dark yellow	Std.	S20	Acrylic, elastomeric coating	Black	Std.

2.3. Natural weathering exposure

The ceramic specimens covered with 20 different acrylic paints were exposed for 18 months to natural weathering at São Carlos, SP, Brazil (22°S, 48°W, and 860m). A low sloped roof surface (8°) was selected, in order to avoid standing water. The nearly horizontal orientation was chosen to maximize the effect of soiling in a short testing period even though the effect of solar radiation can be underestimated (Figure 1).



(a) (b)

Fig. 1. (a) low sloped roof with exposed specimens; (b) detail of evaluated specimens.

São Carlos presents mild weather conditions of hot and rainy summer and cold and dry winter, with average temperatures from 12ºC to 27ºC, respectively. Weather conditions were continuously monitored on site by a weather station (ambient temperature, relative humidity, daily average global solar radiation, and rainfall). Solar reflectance and appearance change were assumed as main evaluation criteria for durability. The SR represents the energy performance of materials while the appearance is more linked to the aesthetic value. Soiling is expected to be one of the main factors responsible for the reflectance loss and its effect has to be distinguished from the contribution due to other weathering agents like solar radiation, temperature and relative humidity. In this procedure, it was possible to quantify, for the considered set of specimens, the natural aging due to the combined actions of weathering and soiling by monitoring reflectance loss on soiled specimens. The coatings reflectance was measured in laboratory before the exposure (new specimens), and every three months after, after the exposure (aged specimens), paying attention during the handling and the shipping in order to avoid drop of dust from the surface.

3. Test results

The spectral reflectance curves of the new and aged samples are presented in Figures 2 and 3, and the solar reflectances are presented on Figure 4a and 4b.

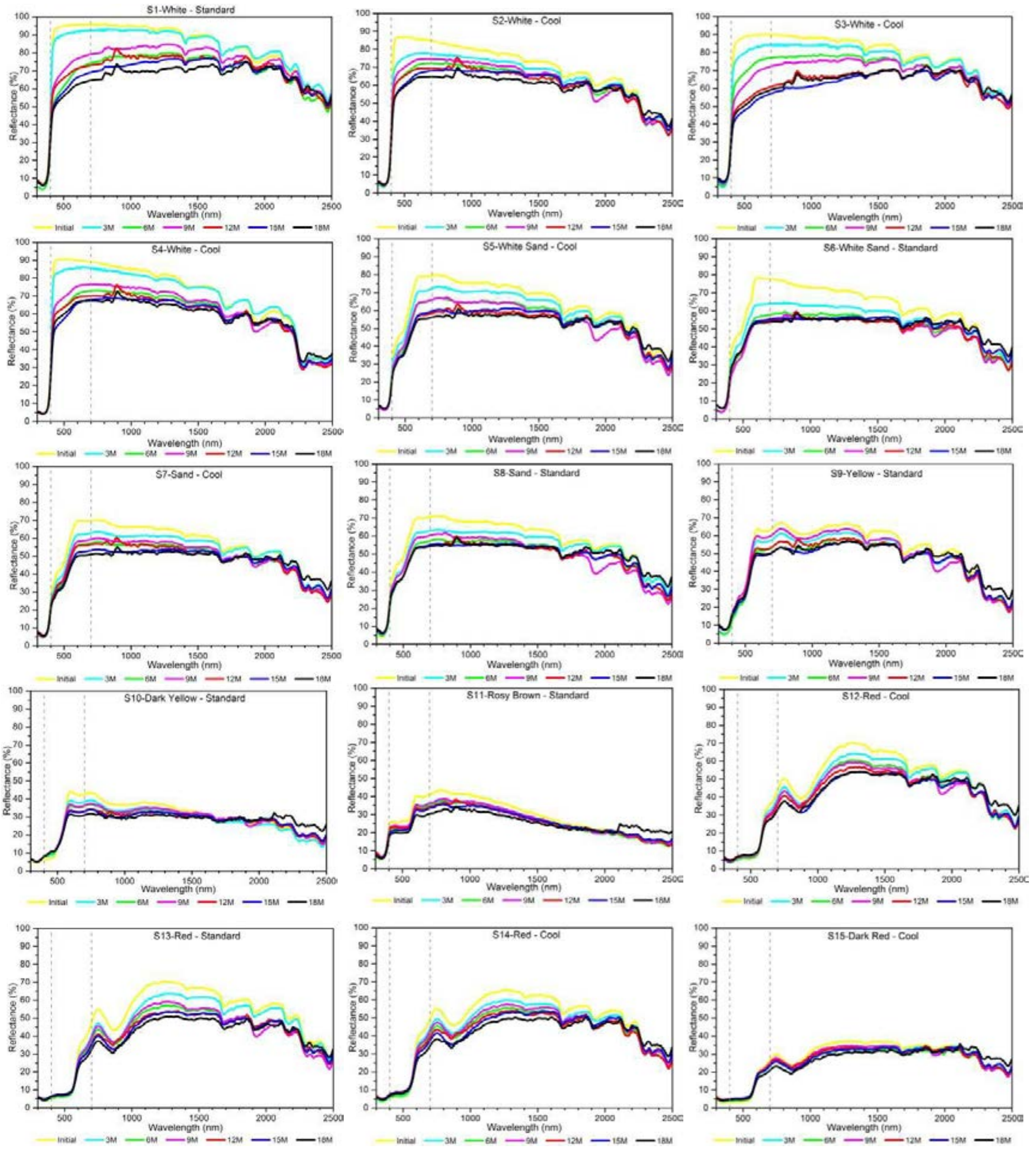


Fig. 2. Spectral reflectances of coatings S1 to S15, when new and after 3, 6, 9, 12, 15 and 18 months of natural weathering.

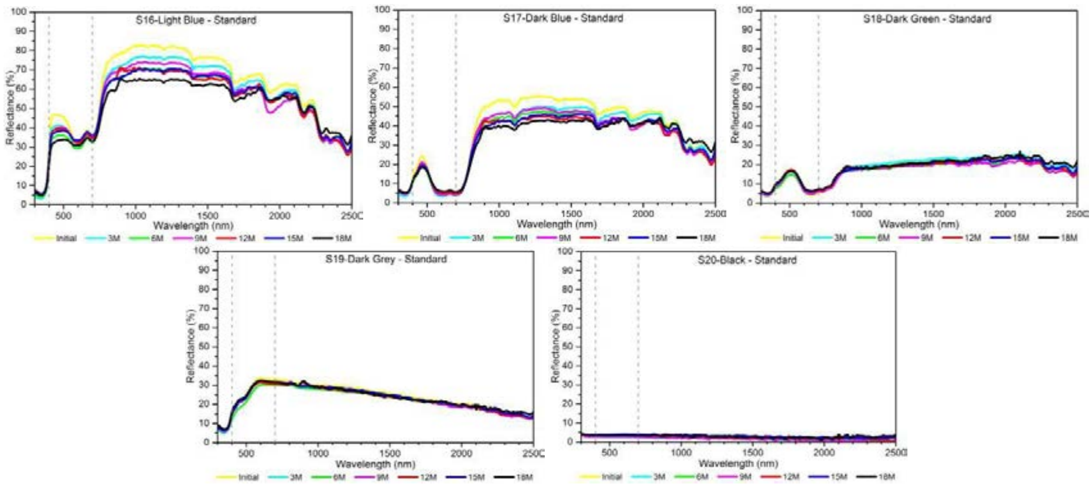
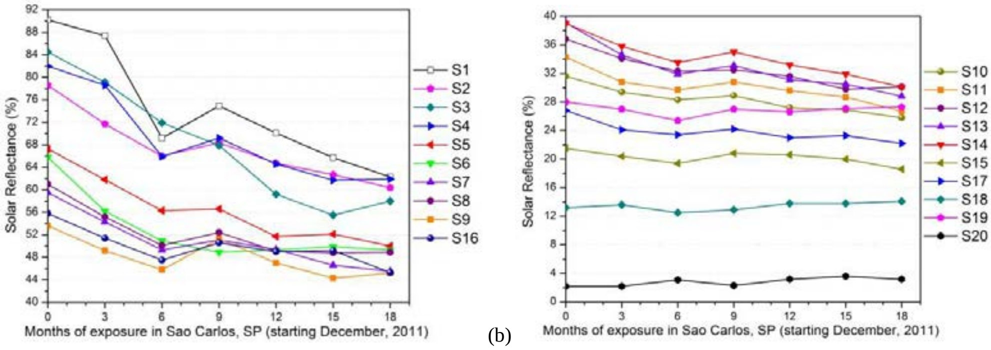


Fig. 3. Spectral reflectances of coatings S16 to S20, when new and after 3, 6, 9, 12, 15 and 18 months of natural weathering.



(a) (b)

Fig. 4. Solar reflectances vs. time for the most-reflective coatings (a) and the least-reflective coatings (b).

Figures 4a and 4b show how the solar reflectance changed with time in this experiment for the weather conditions of Sao Carlos, SP. During the first six months there is a significant reduction which is related to the weathering of the samples. The reflectance changes are mainly due to dust accumulation during the dry period in Sao Carlos, followed by dust removal by rainfall after the winter (month 9, with an increase on the SR).

The results indicated a reduction of the solar reflectance for all samples exposed to natural weathering during 18 months, with exception for coatings S18 (dark green) and S20 (black), which presented an increase of 0.9% and 1% on the solar reflectance, respectively. In this case, the effect of UV radiation is more significant, and for this reason darker colors are more affected by UV radiation because of the degradation. On the other hand, this effect indicates that the accumulating dust is more reflective than black, as expected. Comparing cool versus standard coatings with the same color, cool samples number S5 and S7 presented a higher reduction in the solar reflectance (17.3% and 14%, respectively) compared to the standard ones S6 and S8 (16.5% and 12.1%, respectively). On the other hand, the cool coating S12 presented lower reduction (6.7%) in the solar reflectance when compared with the standard coating with the same color (S13, 10.3%). The reduction on the solar reflectance (difference between initial Solar Reflectance and after 18 months) was more evident for coatings with light colors, with higher reduction for samples S1 (27.9%), S3 (26.9%), and S4 (20.1%), all white coatings. For darker coatings, the reduction was more evident for the infrared portion of the solar spectrum, without expressive differences for the visible spectrum. Beside weather conditions, also soiling (dust and soot deposition, biological growth, etc.) have a huge effect on white coatings. The combined actions of weathering and soiling on the samples can be mainly observed from the difference between the spectral reflectance in the visible portion of the solar spectrum (Fig. 2 and 3). This reduction confirms the effect of soiling on the surface appearance, from clear white to a darker surface.

4. Conclusions

In this work, natural aging tests were performed on specimens of cool and standard colored coatings exposed to natural weathering. Their spectral and solar reflectances were measured in laboratory in order to point out the effect of reflectance variation over time. The results indicated the reduction of the solar reflectance for the coatings exposed to natural weathering after 18 months. This reduction was mainly influenced by weather conditions (solar radiation, rain, temperature, etc.) and soiling (dust and soot deposition), and it was more significant for coatings of light colors. The soiling accumulation on the surface reduces the coatings solar reflectance after months of exposure to natural weathering. On the other hand, two samples of dark colors (black and dark green) presented an increase on the solar reflectance, result mainly of the UV radiation effect and the lower solar reflectance of dust deposition when this is compared to the solar reflectance of dark colors.

Thus, this study demonstrated that the exposure of roof surfaces to environmental agents changes the roofs initial solar reflectance considerably during the first six months, and this effect can be higher for rougher surfaces. The research results suggest the need of developing white coatings able to maintain their reflective properties over time. In this case, the need of periodical roof maintenance is reduced, increasing the potential of long term solar radiation reflection by these surfaces, and the reduction of buildings heat gains. The reduction of heat gains is more effective for insulated building assemblies, as usual in Brazil.

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References

[1] Suehrcke H, Peterson EL, Selby N. Effect of roof solar reflectance on the building heat gain in a hot climate. *Energy and Buildings* 2008, 40; 2224-2235.

[2] Taha H, Akbari H, Rosenfeld A, Huang J. Residential cooling loads and the urban heat island – the effects of albedo, *Building and Environment* 1988, 23:271-83.

[3] Givoni B. *Climate considerations in building and urban design.* New York: Van Nostrand Reinhold; 1998.

[4] Dornelles KA, Roriz V, Roriz M. Determination of the solar absorptance of opaque surfaces. In: *24th International Conference on Passive and Low Energy Architecture*, 2007, Singapore. Proceedings of the 24th PLEA. 2007,1:452-9.

[5] Synnefa A, Santamouris M, Akbari H. Estimating the effect of using cool coatings on energy loads and thermal comfort in residential buildings in various climatic conditions. *Energy and Buildings* 2007,39:1167–74.

[6] Revel GM et al. Nanobased coatings with improved NIR reflecting properties for building envelope materials: development and natural aging effect measurement. *Cement Concrete Composites* 2013,36:128-35.

[7] Levinson R, Berdhal P, Akbari H. Solar spectral optical properties of pigments - part 1: model for deriving scattering and absorption coefficients from transmittance and reflectance measurements. *Solar Energy Materials & Solar Cells* 2005,89:319-49.

[8] Berdhal P, Akbari H, Levinson R, Jacobs J, Klink F, Everman R. Three-year weathering tests on asphalt shingles: solar reflectance. *Solar Energy Materials & Solar Cells* 2012,99:277-81.

[9] Sleiman M et al. Soiling of building envelope surfaces and its effect on solar reflectance-part I: analysis of roofing product databases, *Solar Energy Materials and Solar Cells* 2011,95:3385-99.

[10] Berdahl P, Akbari H, Levinson R, Miller WA. Weathering of roofing materials – an overview, *Construction and Building Materials* 2008,22:423-33.

[11] Cheng M, Miller W, New J, Berdahl P. Understanding the long-term effects of environmental exposure on roof reflectance in California, *Construction and Building Materials* 2012,26:516–26.

[12] Bretz S, Akbari H. Long-term performance of high-albedo roof coatings. *Energy and Buildings* 1997,25:159-67.

[13]ASTM *E903-96: standard test method for solar absorptance, reflectance, and transmittance of materials using integrating spheres.* ASTM International, 1996.

[14] ASTM *G173-03: standard tables for reference solar spectral irradiances – direct normal and hemispherical on 37° tilted surface.* ASTM International, 2003.